6.0 DREDGING AND EXCAVATION

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HIGHLIGHTS

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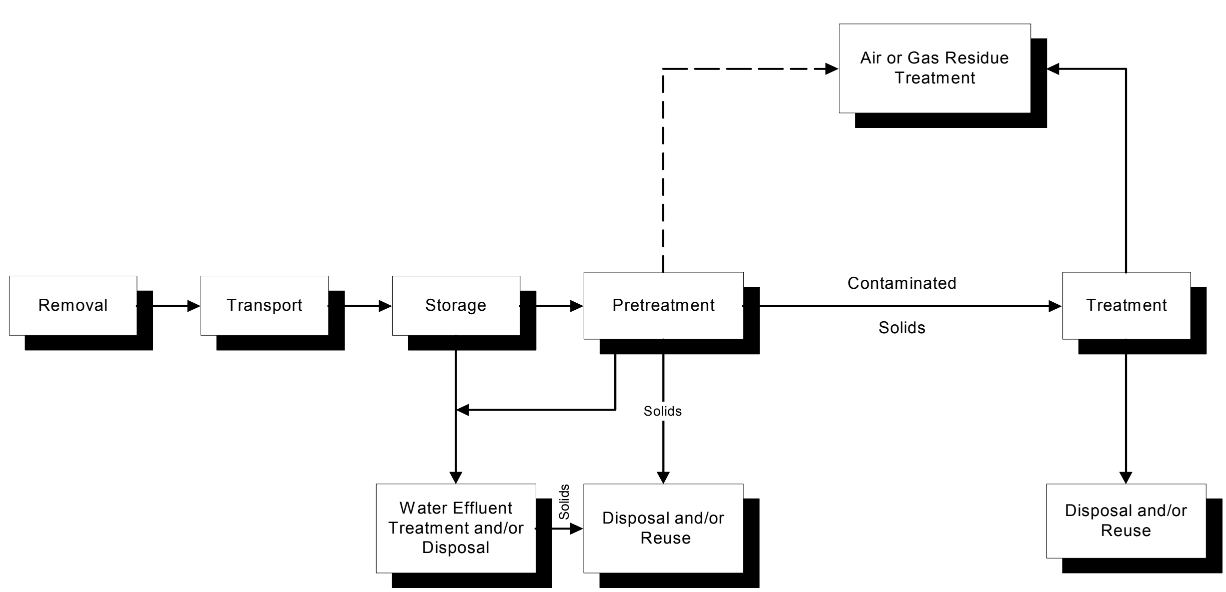
6.0 DREDGING AND EXCAVATION

6.1 INTRODUCTION

Dredging and excavation are means of removing contaminated sediment from a waterbody, either while it is submerged (dredging) or after water has been diverted or drained (excavation). Both methods necessitate transporting the sediment to a location for treatment and/or disposal of the sediment. They also frequently need treatment of water from dewatered sediment prior to discharge. Sediment is dredged on a routine basis at numerous locations for the maintenance of navigation channels. Use of the term environmental dredging has evolved in recent years to characterize dredging performed specifically for the removal of contaminated sediment. The objective of navigational dredging is to remove sediment as efficiently and economically as possible to maintain waterways for recreational, national defense, and commercial purposes. Environmental dredging is intended to remove sediment contaminated above certain action levels while minimizing the spread of contaminants to the surrounding environment (NRC 1997).

The components to be evaluated when considering dredging or excavation as a cleanup method are removal, transport and storage, treatment (pretreatment, treatment of decant and/or dewatering effluents and sediment, if necessary), and disposal (liquids and solids). Highlight 6-1 provides a flow diagram of the steps in a typical dredging or excavation alternative. In its simplest form, a dredging or excavation project may consist of as few as three of the components shown in Highlight 6-1. A complex project may include all of these components.

Highlight 6-1: Example Flow Diagram for Dredging/Excavation



Sediment removal by dredging or excavation is the most frequent cleanup method for sediment used by the Superfund program in the past. Dredging or excavation have been selected as a cleanup method for contaminated sediment at more than 100 Superfund sites as of 2001 (some as an initial removal action). At about 15 to 20 percent of these sites, an in-situ method was also selected for sediment at part of the site. In general, project managers should evaluate each of the three cleanup methods: monitored natural recovery, in-situ capping, and removal through dredging or excavation, at every sediment site at which they may be appropriate.

Project managers should also refer to the U.S. Environmental Protection Agency's *Assessment and Remediation of Contaminated Sediments (ARCS) Program Remediation Guidance Document* (U.S. EPA 1994b) and *Handbook:Remediation of Contaminated Sediments* (U.S. EPA 1991b), and the National Research Council's (NRC's) *Contaminated Sediments in Ports and Waterways: Cleanup Strategies and Technologies* (NRC 1997) for detailed discussions of the processes and technologies available for dredging and excavation. The project manager should evaluate the entire removal process with a coordinated systems approach. Efficient coordination of each component is important for a cost-effective cleanup.

6.2 ADVANTAGES AND DISADVANTAGES

One of the principal advantages of removing contaminated sediment from the aquatic environment is that , where it is done effectively, sediment removal may result in the least uncertainty about long-term effectiveness of the cleanup, particularly regarding future environmental exposure to contaminated sediment. Removal of contaminated sediment can minimize the uncertainty associated with predictions of sediment bed or in-situ cap stability and the potential for exposure and transport of contaminants.

Another principal advantage of removal of contaminated sediment is the flexibility it leaves regarding future use of the waterbody. In-situ cleanup methods such as monitored natural recovery and capping frequently need institutional controls which limit waterbody uses. Sediment removal usually requires fewer institutional controls because larger amounts of contaminants do not remain in place in the aquatic environment.

Another advantage, where dredging residuals are low, concerns the time to achieve remedial action objectives. Active cleanup methods such as sediment removal and capping may reduce risk more quickly by achieving faster reductions in sediment concentrations. Contaminant uptake can be limited or controlled by disposing the dredged or excavated material in an alternate setting, such as an engineered landfill, upland or nearshore confined disposal facility (CDF), or contained aquatic disposal (CAD). Also, sediment removal is the only cleanup method which allows for treatment and/or beneficial reuse of dredged or excavated material. Treatment of contaminated sediment can also reduce the demands on limited landfill disposal capacity.

There are also significant disadvantages to sediment removal. Implementation of dredging or excavation is usually more complex and costly than monitored natural recovery or in-situ capping because of the removal technologies themselves (especially in the case of dredging) and the need for transport, storage, treatment (where applicable), and disposal. Treatment technologies for contaminated sediment offer implementation challenges because of limited full-scale experience and cost. Disposal capacity may be limited in existing municipal or hazardous waste landfills and it may be difficult to site new local disposal facilities.

Another disadvantage of sediment removal is the residual contamination left following removal, especially when dredging is used. No removal technology can remove every particle of contaminated sediment, and especially where work is conducted under water, there can be significant uncertainties concerning the extent of residuals. Residual contamination is likely to be greater in the presence of cobbles, boulders, or buried debris, in high energy environments, at greater water depths, and where contaminated sediment directly overlies bedrock or a hard bottom. These complicating factors can make the sediment removal process and achievement of remediation goals difficult and costly.

Another disadvantage of dredging includes the increased potential for contaminant losses through resuspension and, generally, to a lesser extent through volatilization. Resuspension of sediment from dredging will result in both dissolved and particle-associated releases to the water column. Resuspended particulate material may be redeposited at the dredging site or, if not controlled, transported to other locations in the waterbody downstream. Some resuspended contaminants may also dissolve into the water column where they are available for uptake by biota. While aqueous resuspension is much less of a concern during excavation, there may be increased concern with releases to air. Losses at the disposal or treatment site may include effluent or runoff discharges to surface water, leachate discharges to ground water, or volatile emission to air. Each component of a sediment removal alternative necessitates additional handling of the material and presents a possibility of contaminant loss.

Finally, short-term disruption of the benthic environment is unavoidable during dredging or excavation and includes at least a temporary destruction of the aquatic community and habitat within the remediation area. If removed sediment is to be disposed of in an in-water disposal site, there may be additional impacts to sensitive ecological environments in or near the in-water disposal site.

Where it is feasible, excavation sometimes has advantages over dredging for the following reasons:

- It is difficult to visually observe the removal operation underwater. Although in some cases diver-assisted hydraulic dredging or video-monitored dredging can be used to guide the removal operation, turbidity, safety and other constraints typically make it necessary for dredging to be performed without visual assistance;

- Water flow in the dredged area during removal may result in greater potential for waterborne releases; and

- Water bottom conditions (e.g., debris) and sediment characteristics (e.g., grain size and specific gravity) typically require greater consideration than for excavation.

However, site preparation for excavation can be more lengthy and costly than for a dredging project due to the need for dewatering or water diversion.

6.3 EXCAVATION TECHNOLOGIES

Excavation of contaminated sediment generally involves isolating the contaminated sediment from the overlying waterbody, pumping or diverting water from the area, and managing any continuing inflow followed by sediment excavation using conventional dryland equipment. However, excavation may be possible without water diversion in some areas such as wetlands during dry seasons or while the sediment and water are frozen. Typically, excavation is performed in shallow waterbodies or near shore areas.

Prior to pumping out the water, the area is isolated using the following:

- Sheet piling;
- Earthen dams;
- Rerouting the waterbody using temporary dams or pipes; or
- Permanent relocation of the waterbody.

Sediment isolation using sheet piling commonly involves driving interlocking metal plates (sheet piles) into the subsurface, and thereby either blocking off designated areas or splitting a stream down the center. Highlight 6-2 shows an example of where this has been used. Sheet piling may not be feasible where bedrock or hard strata are present at or near the surface. If a stream is split down its center, then one side of the stream may be excavated in the dry. When the excavation of the first side of the stream is completed, water may be diverted back to the excavated side and sediment on the other side may be excavated. Temporarily rerouting a waterbody with dams is sometimes done for small streams or ponds (Highlight 6-3). This includes the use of temporary dams to divert the water flow allowing excavation of contaminated sediment. The ability and cost to provide hydraulic isolation of the contaminated area during remediation is a major factor in selecting the appropriate removal technology.

Once isolated, standing water within the excavation area will need to be removed. As surface water flows are eliminated ground water may infiltrate the confined area. The ground water can be collected in sumps or dewatering wells. After collection, the ground water should be characterized, managed, treated (if necessary), and discharged to an appropriate receiving waterbody. Management of water within the confined area is an important logistical and cost factor that can influence the decision of wet versus dry removal techniques.

Isolation and dewatering of the area is normally followed by excavation using conventional earthmoving equipment such as a backhoe or dragline. When the excavation activities are complete, temporary dam(s) or sheet piling(s) are removed and the waterbody is restored to its original hydraulic condition. The stream bank and bed may need to be restabilized or restored upon completion of the remediation project depending on applicable regulations.

Another less common type of excavation project involves permanent relocation of a waterbody (Highlight 6-3). The initial phases of such a project may be similar to excavation projects that temporarily reroute a waterbody. However, in a permanent stream relocation project, a replacement

Highlight 6-2: Excavation Following Isolation Using Sheet Piling

Source: Pine River/Velsicol, EPA Region 5

stream is constructed before the original waterbody is capped and converted into an upland area. Because the original waterbody is covered over, direct exposure to residual contamination is reduced or eliminated.

Excavation may also include excavation of sediment in areas that experience occasional dry conditions, such as intermittent streams and wetlands. These types of projects are logistically similar to upland construction projects and frequently use conventional earthmoving equipment.

6.4 DREDGING TECHNOLOGIES

Dredging projects are conducted underwater. Dredging involves mechanically penetrating, grabbing, raking, cutting, or hydraulically scouring the bottom of a waterway to dislodge the sediment. Once dislodged, the sediment may be removed from a waterway either mechanically(with buckets) or hydraulically (by pumping). Therefore, dredges may be categorized as either mechanical or hydraulic depending on the basic means of moving the dredged material. Some dredges employ pneumatic (compressed air) systems to pump the sediment out of the waterway (U.S. EPA 1994b).

6.4.1 Mechanical Dredging

The fundamental difference between mechanical and hydraulic dredging equipment is the form in which the sediment is removed. Mechanical dredges offer the advantage of removing the sediment at nearly the same solids content and, therefore, volume as the in-situ material. Little additional water is

Highlight 6-3: Permanent or Temporary Rerouting of the Waterbody

A: Permanent River Relocation – Triana/Tennessee River Site

The Triana/Tennessee River Site consists of an 11-mile stretch of two tributaries, the Huntsville Spring Branch and Indian Creek, which both empty into the Tennessee River. Remedial actions involved rerouting of the channel in Huntsville Spring Branch (HSB mile 5.4 to 4.0), the filling and burial in place of the DDTR (dichloro diphenyl trichloroethane and its metabolites) in the old channel, the construction of diversion structures at the upper and lower end of the stream to prevent stream reversion to the former stream channel, and the diversion of storm water runoff to prevent flow across the filled channel. Remedial actions for HSB mile 4.0 to 2.4 consisted of constructing four diversion structures; excavating a new channel between HSB mile 3.4 and 2.4; filling three areas; constructing a diversion ditch around the fill areas; and excavating portions of the sediment from the channel.

These remedial actions effectively isolated in place 93% of the DDTR in the Huntsville Spring Branch-Indian Creek system of the Tennessee River. These remedial actions began on April 1, 1986, and were completed on October 16, 1987. Through March 1, 2001, the remedial actions have been inspected yearly by a federal and state Review Panel. The remedial action has not required any repair of the structures to maintain their integrity, and monitoring has shown that DDTR concentrations in fish and water continue to decline.

B: Temporary Re-Routing of a River – Bryant Mill Pond Project at the Allied Paper, Inc./Portage Creek/Kalamazoo River Site

In EPA Region 5, an EPA-conducted removal and onsite containment action removed polychlorinated biphenyls (PCBs)-contaminated sediments from the Bryant Mill Pond area of Portage Creek. During the removal action, that was conducted from June 1998 - May 1999, Portage Creek was temporarily diverted from its normal streambed so that 150,000 cu yds of the creek bed and floodplain soils could be excavated using conventional excavation equipment. PCB concentrations remaining after the removal action were below 1 ppm.

Source: U.S. EPA Region 5

entrained with the sediment as it is removed. Thus, the volumes of contaminated material and process water to be disposed, managed, and/or treated are minimized. Major types of mechanical dredges that have been used in environmental dredging include clamshell bucket (including specialized enclosed clamshell buckets) and backhoes.

Redesigned environmental clamshell dredges address a number of issues often raised relative to remedial dredging including contaminant removal efficiency, sediment resuspension, and overall cost. A new technology tested at the New Bedford Harbor Superfund site in Massachusetts involved precise positioning of the dredging apparatus to minimize over-dredging, a sealed horizontal profiling clamshell bucket to minimize resuspension, and a water recirculating system that reduces water treatment for the hydraulic dredge material pipeline system. Results indicate that PCB-contaminated sediment removal efficiency was very high (> 97 percent) and that resuspension due to dredging was almost non-detectable. Highlight 6-4 shows two examples of mechanical dredges including the type used at New Bedford.

Highlight 6-4: Examples of Mechanical Dredges

Note: A = Use of specially designed “environmental” mechanical dredges cam reduce suspension (Source: Cable Arm, Corp.)
B = New Bedford Site; Bean Company prototype low-resuspension mechanical dredge (Source: Barbara Bergen, U.S. EPA)

6.4.2 Hydraulic Dredging

Hydraulic dredges remove and transport sediment in the form of a slurry through the addition of high volumes of water at some point in the removal process (Zappi and Hayes 1991). The total volume of material processed may be greatly increased and the solids content of the slurry may be considerably less than that of the in-situ sediment although solids content varies between dredges (U.S. EPA 1994b). The excess water is usually discharged as effluent at the treatment or disposal site and may need treatment prior to discharge. Hydraulic dredges may be equipped with rotating blades, augers, or high-pressure water jets to loosen the sediment (U.S. EPA 1995b). The ARCS *Remediation Guidance*

Document (U.S. EPA 1994b) contains figures and summaries of dredge capabilities for several commonly available hydraulic dredges. The hydraulic dredges most commonly used in the U.S. are the conventional cutterhead dredge and the horizontal auger.

Certain hydraulic dredges such as the modified dustpan dredge, cleanup dredge, horizontal profiling grab dredge, Eddy pump, and matchbox dredges, have been specifically developed to reduce resuspension during the removal process. Redesigned hydraulic dredges have recently been tested that can move sediment with less water and others that recycle the water used to move the sediment. Highlight 6-5 presents examples of hydraulic dredges.

6.4.3 Dredge Equipment Selection

The selection of appropriate dredging equipment is essential for an effective dredging operation. The following factors should be evaluated:

- Solids Concentration: In most cases it is preferable to use a dredging system that is capable of delivering material at high solids concentrations to minimize costs for handling, treating, and disposal of water and sediment. However, in some cases the advantages of slurried sediment that may be transported by pipeline may override these considerations;

- Production Rate: A high production rate or large dredge may be necessary to complete large projects within acceptable time frames or necessary to cut through harder sediment. Alternatively, a low production rate may be beneficial to minimize sediment resuspension or because of constraints caused by sediment transport, treatment, or disposal components, or when rocks or debris are present in the sediment;

- Dredging Accuracy: Precise control of operational dredging depth is particularly important when dredged sediment is to be handled in expensive treatment and disposal facilities (Averett et al. 1990). The vertical and lateral accuracy of the dredge is important to ensure that contaminated sediment is removed, while minimizing the amount of clean sediment removed;

- Water Depth: Dredges are limited to dredging areas with an adequate depth of water to accommodate the draft of the dredging vessel. This factor becomes important when contaminated sediment is located outside of navigable waterways. Some dredging equipment may be operated from land to access sediment in shallow waterways. The maximum depth to which dredges reach may be a limiting factor. Some dredges are limited by the length of the dredging arm or ladder. Hydraulic dredging in very deep water (i.e., greater than 20 meters) may need submerged pumps or remotely operated dredges;

- Ability to Handle Large or Dangerous Debris: Sediment, especially in urban areas and cargo loading/unloading areas may contain very large debris (e.g., greater than 0.5 meters in any dimension) which can only be removed mechanically. Mechanical dredges generally remove large debris with the sediment, however they may produce greater

Highlight 6-5: Examples of Hydraulic Dredges

Note: A = Fox River, WI; horizontal auger hydraulic dredge deployment (Source of photo, Jim Hahnenberg U.S. EPA)
B = Manistique, MI; closeup of twin-vortex pump, hydraulic dredge cutterhead (Source of photo, Ernie Watkins U.S. EPA)
C = Closeup of swinging ladder hydraulic dredge cutterhead (Source of photo, Ellicott Corporation)

turbidity in the process. Dredgeheads equipped with cutters may be able to reduce the size of some debris, such as wood. Although debris that is larger than the diameter of the suction pipe or not cut by the cutter cannot be removed by hydraulic dredges, smaller debris may also clog hydraulic pipelines and damage pumps. At some sites the risk and approach for dealing with buried munitions from past military activities should be evaluated;

- <u>*Sediment Resuspension, Release and Residual Concentration:*</u> Sediment resuspension, contaminant release, and residual sediment concentrations are primary concerns at many sites and may override other factors in selecting a dredge. The degree of resuspension is influenced by both the type of dredge and its operation. Specialty dredges have been designed in recent years to minimize resuspension, although dredge operation is extremely important;

- <u>*Site Restrictions:*</u> Channel widths, surface and submerged obstructions, overhead restrictions, such as bridges, and other site access restrictions may limit the type and size of equipment that can be used. The presence of buried utilities, pipelines, and other infrastructure should also be considered in the evaluation of dredging technologies;

- Compatibility: The overall compatibility of dredging equipment with the transport, treatment, and disposal requirements for the project is critical to an efficient and effective dredging remedy. In most cases it is preferable to use a dredging system that is capable of delivering material at high solids concentrations. This tends to minimize the costs of handling, treating, and disposing of sediment. Mechanically dredged sediment does not need intensive dewatering, which is an expensive pre-treatment process. Mechanical dredging keeps the volume of dredged material to a minimum and greatly reduces the costs of water treatment; and

- Distance to Treatment or Disposal Sites: The distance from the dredging site to the treatment, disposal, or re-handling site affects the method of transport and, hence, the type of dredge. If there is access for a pipeline slurried sediment can be transported by pipeline several kilometers where there is little elevation gain, and can be transported over longer distances with the use of booster pumps. If pipeline transport is not feasible, sediment can be transported at high solids concentrations (e.g., as produced with mechanical or pneumatic dredges) by scows or barges, provided that the water is deep enough for barge transport and there are no other limitations on navigation.

The operational characteristics of conventional mechanical and hydraulic dredges are shown in Highlight 6-6. Highlight 6-7 displays an assessment of various dredges against the factors listed above and additional factors that may be important in dredge selection at some sites. The information in these highlights is intended as general guidelines to help project managers make an initial assessment of dredge capabilities. There are many site specific circumstances that dictate which equipment will work for any given situation. In addition, because new equipment is being continuously developed, project managers will need to consult with experts who are familiar with the latest technologies in order to make a final selection.

Experience has shown that an environmentally effective dredging operation depends on the use of highly skilled dredge operators familiar with the goals of environmental remediation, in addition to close monitoring and management of the dredging operation. For additional advice regarding dredge equipment selection and use project managers should consult professionals in this field and the additional technical documents listed in Appendix D.

6.4.4 Dredge Positioning

A critical element of sediment remediation is the precision of the dredge cut, both horizontally and vertically. Technological developments in surveying (vessel) and positioning (dredgehead) instruments have improved the dredging process. Vertical control may be particularly important when contamination occurs in a relatively thin or uneven layer. Video cameras may be used to continuously monitor dredging operations. The working depth of the dredgehead may be measured using acoustic instrumentation and by monitoring dredged slurry densities. In addition, surveying software packages may be used to generate pre- and post-dredging bathymetric charts, determine the volume of dredged sediment, locate obstacles, and calculate linear dimensions of surface areas (St. Lawrence Centre 1993).

Highlight 6-6: Operational Characteristics of Various Dredges

Dredge Type[1]	Percent Solids by Weight	Range of Production Rates (cubic m/hr)[2]	Dredging Accuracy[3]		Operational Dredging Depth		Debris Removal (+ indicates capability)
			Vertical (cm)	Horizontal (m)	Minimum (m)[4]	Maximum (m)	
Clamshell or Grab	Near in-situ	20-500	10-60	0.1-0.3	--	50	+
Backhoe	Near in-situ	20-150	5-30	0.05-0.15	--	15	+
Enclosed Bucket	Near in-situ	20-500	5-30	0.1-0.3	--	50	
Bucket/pump	Near in-situ	20-150	5-30	0.05-0.15	--	15	
Cutterhead (6-8 in.)	10-20	20-100	5-30	0.1-0.5	1.2	4	
Cutterhead (10-12 in.)	10-20	60-500	5-30	0.1-0.5	1.4	8	
Cutterhead (14-18 in.)	10-20	200-900	5-30	0.1-0.5	1.5	12	
Horizontal Auger (6-18 in.)	10-30	50-100	5-15	0.15-0.5	0.5	5	
Pneumatic	25-40	50-300	5-30	0.1-0.3	--	45	
Diver Assisted Vacuum	5-10	10	--	0.15	0.5	30	
Plain Suction	5-15	20-4000	5-30	0.1-0.5	2	19	
Dry Excavation	In situ or greater	10-500	10	0.1	0	Stability Limitations	+

[1] This table only includes dredge sizes normally considered for environmental projects. Larger dredge sizes commonly used for navigation dredging are available.
[2] Production rates include both environmental and navigational dredging. Removal of contaminated sediments tend toward the low end of the range.
[3] Where a range is shown for positioning accuracy, the lower value reflects use of state-of-the-art electronic positioning equipment to define dredgehead position employed under favorable conditions, while the upper value reflects use of electronic positioning for the vessel only with visual indicators of dredgehead positioning with respect to the vessel.
[4] Note that the minimum operating depth limitations may be overcome by an excavation sequence from deeper water into the area to be dredged.

Sources: U.S. EPA 1994b, USACE 1983, Bray 1997, Herbich 1992

Highlight 6-7: Selection of Dredges for Contaminated Sediment Removal

Dredging Issue/ Concern/ Constraint	Mechanical Dredges				Hydraulic Dredges					
	Clamshell	Backhoe	Enclosed Bucket	Bucket/ Pump	Cutterhead	Horizontal Auger	Pneumatic	Diver-Assisted Vacuum	Plain Suction	Dry Excavation
Sediment resuspension[1]	−	−	+	+	+	0	+	+	+	+
Volatiles control	−	−	+	+	+	+	+	+	+	−
Low clean-up targets	−	−	−	−	+	+	+	+	+	+
Spillage	−	−	+	+	+	+	+	+	+	+
Transport by pipeline	−	−	−	−	+	+	+	+	+	−
Transport by barge	+	+	+	−	−	−	−	−	−	+
High solids concentration	+	+	+	+	−	−	−	−	−	+
Vertical cut control	−	+	−	−	+	+	−	−	−	+
Lateral cut control	−	+	−	+	−	+	−	−	−	+
Positioning support required	0	0	0	0	+	+	0	0	0	+
Shallow water (<3 ft)	−	−	−	+	+	+	−	+	+	+
Deep water (>20 ft)	+	+	+	0	0	−	+	−	0	−
Current/tides[2]	+	+	+	−	−	−	−	−	−	0
Piers and utilities	+	+	+	−	−	−	−	+	+	+
Debris/boulders/rocks[3]	+	+	−	−	−	−	−	+	−	+
Vegetation removal[4]	+	+	+	+	−	−	−	−	−	+
Production rate	+	+	+	−	+	+	−	−	−	+
Hardpan (native clay/till)	+	+	−	−	+	−	−	−	−	+
Thin lift for removal	−	−	−	−	+	+	+	+	+	+
Availability	+	+	+	+	+	+	+	+	+	+
Portability	−	−	−	+	+	+	−	+	−	0
Positioning control	−	+	+	+	−	+	−	+	−	+

	Mechanical Dredges				Hydraulic Dredges						
Dredging Issue/ Concern/ Constraint	**Clamshell**	**Backhoe**	**Enclosed Bucket**	**Bucket/ Pump**	**Cutterhead**	**Horizontal Auger**	**Pneumatic**	**Diver-Assisted Vacuum**	**Plain Suction**	**Dry Excavation**
Operator health & safety	−	−	−	+	+	+	+	+	+	−

Note:
+ indicates a technology which may generally be favorable for addressing this issue or concern
− indicates a technology which may not be generally favorable for addressing this issue or concern
0 indicates a technology which may be neutral for addressing this issue or concern

[1] Conventional backhoes are normally used for dry excavation and can cause resuspension when used in wet environments. Special enclosed backhoes can be used if resuspension is a problem.
[2] Most mechanical dredges are able to maintain their position in currents and tides better than hydraulic dredges.
[3] In general mechanical dredges have advantages in removing debris and boulders, although they may have trouble closing because of these obstructions, resulting in leakage of water and sediment. Hydraulic dredges can pass moderate sized rocks and can suction around boulders.
[4] Many hydraulic dredges have problems removing vegetation without becoming clogged.

Digital positioning systems are available that enable dredge operators to follow a complex sediment contour (Van Oostrum 1992).

The horizontal position of the dredge should be continuously monitored during dredging. Satellite- or transmitter-based positioning systems, such as differential global positioning systems (DGPS) should be used to define the dredge position. In some cases, however, the accuracy of these systems is inadequate for precise dredging control. Where the accuracy of site characterization data or the high cost of disposal warrant very precise control, it is possible to use optical (laser) surveying instruments set up at one or more locations on shore. These techniques, in conjunction with on-vessel instruments and spuds (if water depths are less than about 50 feet) and anchoring systems may enable the dredge operator to more accurately target specific sediment deposits. The effectiveness of anchoring systems diminishes as water depth increases.

The positioning technology described above enhances the accuracy of dredging. However, project managers should not develop unrealistic expectations of dredging accuracy. Contaminated sediment may not be removed with surgical accuracy even with the most sophisticated equipment. Equipment may not be the only factor affecting the accuracy of the dredging operation. Site conditions (e.g., weather, currents), sediment conditions (e.g., bathymetry, physical characteristics), and the skill of the dredge operator are all important factors. In addition, the distribution of sediment contaminants may only be defined at a crude level and there could be a substantial margin for error. The level of accuracy required for environmental dredging should reflect the accuracy needed to attain the remedial action objectives.

6.4.5 Control of Dredging Losses and Residuals

In environments with significant water movement due to tides or currents, resuspended sediment may be transported away from a dredging site; therefore, limiting resuspension or increasing containment should be an important consideration. Another potential problem may be the volatilization of contaminants that reach the water's surface, either near the dredge site or in a holding facility (Chiarenzeli et al. 1998).

When evaluating short-term effects of dredging, it is important to compare impacts to baseline conditions including water quality impacts due to any natural sediment disruption that would continue to occur if the contaminated sediment was not dredged. All dredges resuspend some sediment during the dredging processes. Some contaminants in the dissolved form and some contaminants associated with resuspended particles will be released and transported away from the dredging site. Monitoring during dredging is critical to evaluate resuspension and its effects on water quality. Much can be done to limit sediment resuspension from conventional dredges without substantial impact upon the efficiency of the dredging operation. Precautions in operation and/or minor plant modifications can be made with only a small increase in cost, however, other factors such as maneuverability requirements, hydrodynamic conditions, and location of the disposal site may dictate the type of dredge that should be used. The strategy for the project manager should be to minimize the resuspension levels generated by any specific dredge type. If conventional dredges are unacceptable, a special purpose dredge may be required. These dredges generally resuspend less material than conventional dredges, but associated costs may be much greater. As in the case of conventional dredges, the selection of a special purpose dredge will likely be dictated by site specific conditions, economics, and availability (Palermo et al. 1998b). The EPA's Office of Research and Development and others are in the process of evaluating resuspension and its effects, both in field and modeling studies. The results of this research should help project managers predict and control effects of resuspension during future cleanup actions.

During dredging volatile contaminants trapped in the sediment may be released to the water column and atmosphere in the vicinity of the dredge and/or at the CDF posing a potential risk to workers and the nearby community. This exposure route may be minimized by reducing dredging production rates so that resuspension is minimalized. Covering the surface of the water with a physical barrier or an absorbent compound may minimize volatilization. At the New Bedford Harbor site, a cutterhead dredge was modified by placing a cover over the dredgehead that retained PCB-laden oils, thus reducing the air concentrations during dredging to background levels (Bergen in preparation). In addition, the CDF that the dredged sediment was pumped into was fitted with a plastic cover to effectively reduce air emissions. To further minimize the potential for volatile releases, dredging operations were conducted during cooler weather periods, such as at night.

During excavation, volatilization could be of greater concern as contaminated materials may be exposed to air. Care should be taken in dewatering activities to ensure that temperatures are not elevated (e.g., cautious application of lime or cement for de-watering), and other control measure should be taken as needed (e.g., foam).

The potential for residual contamination left behind by the dredging operation is dependent on a number of factors including the design and operating mode of the dredgehead, the size of the dredge (e.g. cutterhead diameter), operating parameters (e.g. swing speed, advance rate of the dredge, cutter rotation, and depth of burial of the dredgehead), skill of the operator, sediment physical properties, thickness of the layer to be removed, and site hydrodynamics such as currents and waves. Additional passes of the dredge may be required to achieve the desired results. Placement of a thin layer of clean material designed to mix with underlying sediment is another approach to address the problem of residual sediment. Project managers should conduct a site-specific assessment of anticipated sediment resuspension, contaminant release and transport, and its potential ecological impacts prior to dredging. Also, the project manager should make realistic assumptions regarding residual contamination. Where over dredging is not possible, residual contamination is generally higher than where this practice is possible.

6.4.6 Containment Barriers

Transport of resuspended contaminated sediment released during dredging can often be reduced by using physical barriers around the dredging operation. Barriers commonly used to reduce the spread of contaminants during the removal process include oil booms, silt curtains, silt screens, sheet-pile walls, and cofferdams (U.S. EPA 1994b). Under favorable site conditions these barriers help limit the areal extent of particle bound contaminant migration resulting from dredging resuspension and enhance the long-term benefits gained by the removal process. Conversely, because the barriers contain resuspended sediment they typically increase contaminant concentrations inside the barrier where it may need to be managed.

Structural barriers, such as sheet pile walls, have been used for sediment excavation and in some cases (e.g., high current velocities) for dredging projects. The determination of whether these types of barriers are necessary should be made based on a thorough evaluation of the site. This can be accomplished by evaluating the relative risks posed by the anticipated release of contaminants from the dredging operation absent use of such structural barriers, the predicted extent and duration of such releases, and the potential for trapping and accumulating residual contaminated sediment within the barrier. The project manager should consult the *Risk Assessment and Modeling Overview Document* (U.S. EPA 1993d) and *Estimating Contaminant Losses from Components of Remediation Alternatives for Contaminated Sediment* (U.S. EPA 1996f) for further information about evaluating the need for structural barriers.

Oil booms are appropriate for sediment that may likely release oils or floatables when disturbed. Such booms typically consist of a series of synthetic foam floats encased in fabric and connected with a cable or chains. Oil booms may be supplemented with oil absorbent materials, such as polypropylene mats (U.S. EPA 1994b). However, booms do not aid in retaining the soluble portion of floatables [e.g., polynuclear aromatic hydrocarbons (PAHs) from oils].

Silt curtains and silt screens are flexible barriers that hang down from the water surface. Both systems use a series of floats on the surface and a ballast chain or anchors along the bottom. Although the terms “silt curtain” and “silt screen” may frequently be used interchangeably there are fundamental differences. Silt curtains are made of impervious materials, such as coated nylon, and primarily redirect flow around the dredging area rather than blocking the entire water column. In contrast, silt screens are made from synthetic geotextile fabrics, which allow water to flow through, but retain a large fraction of the suspended solids (Averett et al. 1990). Silt curtains or silt screens may be appropriate when contaminant concentrations are high or site conditions dictate the need for minimal transport of sususpended sediment. A typical configuration of silt curtains or screens is shown in Highlight 6-8.

Silt curtains have been used at many locations with varying degrees of success. For example, silt curtains were found to be effective in limiting suspended solids transport during in-water dike construction of the CDF for the New Bedford Harbor pilot project. However, the same silt curtains were ineffective in limiting contaminant migration during dredging operations at the same site primarily as a result of tidal fluctuation and wind (Averett et al. 1990). Problems were experienced during installation of silt curtains at the General Motors site (Massena, New York) due to high current velocities and back eddies. Dye tests conducted after installation revealed significant leakage and the silt curtains were removed. Sheet piling was then installed around the area to be dredged with silt curtains used as supplemental containment for hot spot areas. A silt curtain/silt screen containment system was effectively applied during dredging of the Sheboygan River in 1990 and 1991, where water depths were two meters or less. A silt curtain was found to reduce suspended solids from approximately 400 milligrams per liter (inside) to 5 milligrams per liter (outside) during rock fill and dredging activities in Halifax Harbor, Canada (MacKnight 1992).

The effectiveness of silt curtains and screens at a sediment remediation site is primarily determined by the hydrodynamic conditions at the site. Conditions that may reduce the effectiveness of barriers include the following:

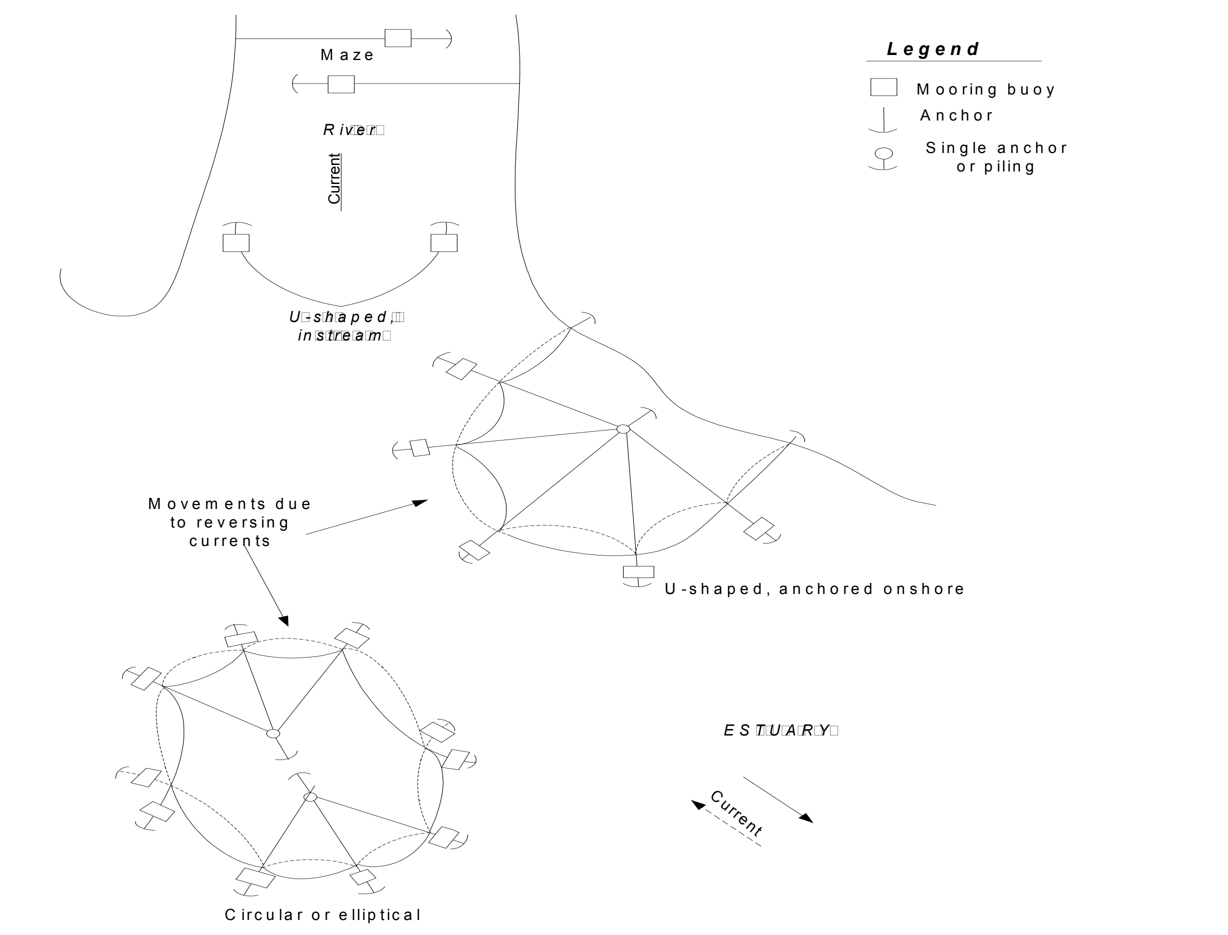
- Strong currents;

- High winds;

- Changing water levels, such as tidal fluctuation;

- Excessive wave height, including ship wakes; and
- Drifting ice and debris.

Highlight 6-8: Typical Configuration of Silt Curtains and Screens



Source: U.S. EPA 1998d

Silt curtains and screens are generally most effective in relatively shallow, undisturbed water. As water depth increases and turbulence caused by currents and waves increases, it becomes difficult to effectively isolate the dredging operation from the ambient water. The St. Lawrence Centre (1993) advises against the use of silt curtains in water deeper than 6.5 meters or in currents greater than 50 centimeters per second.

The effectiveness of containment barriers is also influenced by the quantity and type of suspended solids, the mooring method, and the characteristics of the barrier (JBF Scientific Corp. 1978). To be effective, barriers are deployed around the dredging operation and should remain in place until the operation is completed at that site. For large projects it may be necessary to relocate the barriers as the dredge moves to new areas. Where possible barriers should not impede navigation traffic. Containment barriers may also be used to protect specific areas, for example valuable habitat, water intakes, or recreational areas, from suspended sediment contamination.

6.5 TRANSPORTATION AND STORAGE

After removal, sediment is transported to a disposal, storage, or re-handling area for further processing or final disposal. Transport links all dredging or excavation components and may involve several different technologies or modes of transport. The first element in the transport process is to move sediment from the removal site to the disposal, storage, or re-handling site. Sediment may then be transported for pretreatment, treatment, and/or ultimate disposal (U.S. EPA 1994b).

Modes of transportation may include one or more of the following waterborne or overland technologies:

- Pipeline: Direct placement of material into disposal sites by pipeline is economical only when the disposal and/or treatment site is located near the dredging areas (typically a few kilometers or less unless booster pumps are used). Mechanically dredged material may also be re-slurried from barges and pumped into nearshore disposal sites by pipeline;

- Barge: A re-handling facility located on shore is a commonly considered option. With a re-handling facility, dredging can be accomplished with mechanical (bucket) dredges where the sediment is excavated at near in-situ density (water content) and placed in a scow or barge for transport to the re-handling facility;

- Conveyor: Conveyors may be used to move material from barges to adjacent re-handling facilities or to move material relatively short distances. Materials should be in a dewatered condition for transport by conveyor;

- Railcar: Rail spurs may be constructed to link re-handling/treatment facilities to the rail network. Many licensed landfills have rail links, so long-distance transport by rail is generally an option; and/or

- Truck/Trailer: Dredged material can be re-handled directly from the barges to roll-off containers or dump trucks for transport to a CDF by direct dumping or unloading into a chute or conveyor. Truck transport of treated material to landfills may also be considered. The material should be dewatered prior to truck transport over surface streets. In some smaller sites where construction of dewatering beds may be difficult or the cost of disposal is not great, addition of non-toxic absorbent materials such as lime or cement may be feasible.

A wide variety of transportation methods are available for moving sediment and residual wastes with unique physical and chemical attributes. In many cases, contaminated sediment is initially moved using waterborne transportation. Exceptions are the use of land-based or dry excavation methods. Hydraulic dredges produce contaminated dredged-material slurries that can be transported by pipeline to either a disposal or re-handling site. Mechanical removal methods typically produce dense, contaminated material that is hauled by barge, railcar, truck/trailer, or conveyor systems. The feasibility and costs of transportation are frequently influenced by the scale of the remediation project. Key resources for information on transport methods are listed in Appendix D.

Storage of contaminated sediment may also be necessary to dewater prior to upland disposal or to allow for pretreatment and equalization prior to treatment. For example, a temporary CDF may be designed to store material for periods when dredging or excavation is not possible due to weather or environmental concerns, while the treatment process may continue on a near 24-hour operating schedule. Storage may be temporary (e.g., pumping onto a barge with frequent off-loading) or more permanent (e.g., moving the sediment to a land-based CDF where it may be de-watered and treated).

The project manager should consider potential contaminant losses to the water column and atmosphere during transportation to the treatment or disposal site, and temporary storage, if applicable. The risks of potential exposures during transport, through volatilization, water loss, or accidental spills during movement should also be evaluated.

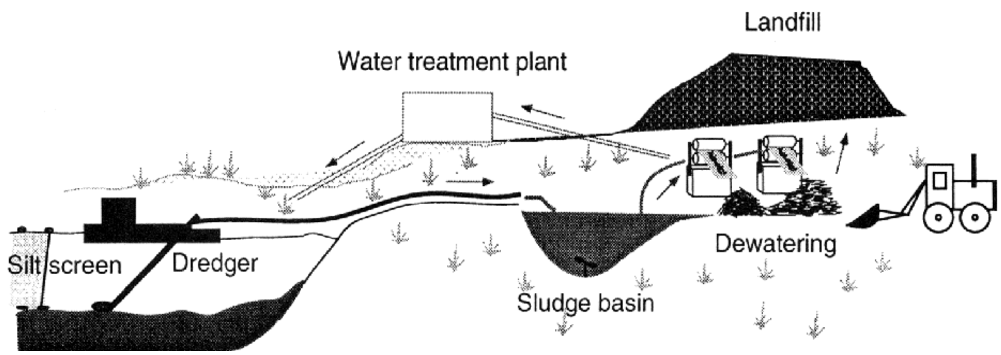
The risks associated with a temporary storage site are similar to those associated with CDFs, as discussed in section 6.7. In particular, in-water temporary CDFs can prove to be attractive nuisances, especially to waterfowl, by providing attractive habitat that encourages use of the CDF by wildlife and present the opportunity for exposure to contaminants. For highly contaminated sites, it may be necessary to provide a temporary cover or sequence dredging to allow for coverage of highly contaminated sediment with cleaner sediment to minimize short-term exposures. This method of control has proven effective for minimizing exposures at upland sanitary landfills. In addition, because some holding areas may not be designed for long-term storage of contaminated sediment, the risk of contaminant transport to ground water should be evaluated and monitored.

6.6 TREATMENT

The treatment of contaminated sediment is not usually a single process, but often involves a combination of processes to address various contaminant problems, including pre-treatment, operational treatment and/or effluent treatment/residual handling.

Some form of pre-treatment and effluent treatment/residual handling are necessary at almost all sediment removal projects. A typical dewatering process is shown in Highlight 6-9. Sediment treatment processes of a wide variety of types have been applied in pilot-scale demonstrations, and some have been applied full-scale. However, the relatively high cost of most treatment alternatives, especially those involving thermal and chemical destruction techniques, can be a major constraint on their use at the present time (NRC 1997). The base of experience for treatment of contaminated sediment is still limited, as discussed in more detail later in this chapter. Each component of a potential treatment train is discussed below.

Highlight 6-9: Example of Dredging Dewatering Process



6.6.1 Pre-Treatment

Pre-treatment modifies the dredged or excavated material in preparation for final treatment or disposal. When pre-treatment is part of a treatment train, distinguishing between the two components may be difficult and is not always necessary. Pre-treatment is generally performed to condition the material to meet the chemical and physical requirements for treatment or disposal; and/or to reduce the volume and/or weight of sediment that requires transport, treatment, or restricted disposal. Pre-treatment processes typically include dewatering and physical or size separation technologies.

Most treatment technologies require that the sediment be relatively homogeneous and that physical characteristics be within a relatively narrow range. Pre-treatment technologies may be used to modify the physical characteristics of the sediment to meet these requirements. Additionally, some pretreatment technologies may divide sediment into separate fractions, such as organic matter, sand, silt, and clay. Often the sand fractions contain lower contaminant levels and may be suitable for unrestricted disposal and/or beneficial use if it meets applicable standards and regulations. Selection factors, costs, pilot-scale demonstrations, and applicability of specific pre-treatment technologies are discussed in detail in EPA (1994b).

6.6.2 Operational Treatment

Depending on the contaminant concentration and composition of the sediment, it may be advisable or necessary to treat the sediment to reduce the toxicity, mobility, or volume of the contaminants before disposal or final placement. In general, treatment processes have the ability to reduce sediment contaminant concentrations, mobility, and/or sediment toxicity by contaminant destruction or detoxification, extraction of contaminants from sediment, reduction of sediment volume or sediment solidification/stabilization.

Treatment technologies for sediment are generally classified as biological, chemical, extraction or washing, immobilization (solidification/stabilization), and thermal (destruction or desorption). In some cases, particle size separation is also considered a treatment technology. Pilot and full-scale treatment processes have been conducted at a variety of sites, although there is limited experience at Superfund sites. Some of these sites are listed in Highlight 6-10. Additional information concerning treatment technologies for contaminated sediment may be found in U.S. EPA Office of Water's *Selecting Remediation Technologies for Contaminated Sediment* (U.S. EPA 1993e) and other references listed in Appendix D.

Bioremediation

Bioremediation is the process in which microbiological processes are used to degrade or transform contaminants to less toxic or nontoxic forms. Bioremediation technologies harness this process by promoting the enzymatic production and microbial growth necessary to convert the target contaminant to non-toxic end products. Biological treatment has been used for decades to treat domestic and industrial waste waters. In recent years, it has been demonstrated as a technology for destroying some organic compounds in sediment.

Microbial degradation of many persistent contaminants in the environment, such as PCBs and PAHs, may be influenced by the compound's toxicity to microbial organisms; microbial feeding strategies, genetic ability to use the contaminant as a source of carbon and energy and the ability of microbes to propagate under site-specific environmental conditions.

Bioremediation often attempts to alter the environmental conditions in the dredged or excavated material to stimulate the development of an appropriate microbial population. Such changes may include adjusting concentrations of nutrients or compounds, pH, oxygen concentration, temperature, or microbial population. The project manager should refer to EPA (1994b), Myers and Bowman (1999), and Myers and Williford (2000) for a summarization of bioremediation technologies and their application under site-specific conditions.

Chemical Treatment

Chemical treatment refers to processes in which chemical reagents are added to the dredged or excavated material for the purpose of contaminant destruction. Contaminants may be destroyed completely, or may be altered to a less toxic form. Averett et al. (1990) reviewed several general categories of chemical treatment. Of the categories reviewed, the following treatments were considered most promising:

- *Chelation:* Formation of a stable complex between a metal cation and a ligand (chelating agent), binding of the metal cation in this stable complex renders it unavailable for further reaction, efficiency varies with the chelating agent and dosage used (U.S. EPA 1994b);

- *Dechlorination:* Removes chlorine molecules from contaminants (e.g., PCBs and dioxins) through the addition of chemical agents under alkaline conditions and increased temperatures (U.S. EPA 1990b, and U.S. EPA 1990c). The process releases steam and volatile organic vapors and the vapors are further treated using activated carbon. The resulting products are generally less toxic than the original contaminants; and

Highlight 6-10: Sediment Treatment Examples

Country/Location	Project Type	Contaminants	Process Options	Scale	Reference
			BIOLOGICAL		
USA/WI Sheboygan River	Remedial (Superfund)	PCBs	Contained land (sheet pile structure)	Pilot	Foster 1991
Canada/ON Hamilton Harbor	Remedial CSTTP	PAHs	Contained land	Pilot	Wardlaw 1993 (personnel communication)
Canada/ON Toronto Harbor	Remedial CSTTP	PAHs	Bioslurry	Pilot	U.S. EPA 1993f
Netherlands Zeeland	Navigation DPTP	PAHs	Land farming	Pilot	Van Dillen and Bruggeman 1992
Milwaukee Harbor	Navigation	PAHs	CDF Management/ Land farming	Pilot	Myers and Bowman 1999
			CHEMICAL		
Canada/ON Hamilton Harbor	Remedial CSTTP	PAHs	Reduction (thermal w/hydrogen)	Pilot	ELI Eco Logic 1992
Netherlands Elburg	Navigation DPTP	PAHs	Wet oxidation	Pilot	Van den Eede 1994
			EXTRACTION		
USA/IN Gr. Calumet	Remedial ARCS/SITE	PCBs, PAHs	Triethyl amine solvent	Pilot	U.S. EPA 1994d
USA/MA New Bedford	Remedial SITE	PCBs	Supercritical propane	Pilot	U.S. EPA 1990a
NY/NJ Harbor	Navigation	Dioxins, PCBs, PAHs	Organic solvent	Pilot	Stern et al. 1994 Jones et al. 1999
Canada/ON Toronto Harbor	Remedial CSTTP	Metals	Acid extraction Chelation	Pilot	U.S. EPA 1993f
			IMMOBILIZATION		
USA/NY Marathon Battery	Remedial Superfund	Metals Cd, Ni	Stabilization	Full	Simmons 1993 (personnel communication)
Belgium Vilvoorde		Metals	Solidification	Full	
USA/NY/NJ Harbor	Navigation	Metals, organics	Stabilization	Full	Stern et al. 1994 Jones et al. 1999
USA/NY Buffalo River	Remedial ARCS	Metals	Solidification (post-thermal desorption)	Pilot	U.S. EPA 1993g

Country/Location	Project Type	Contaminants	Process Options	Scale	Reference
			THERMAL		
USA/LA Bayou Bonfouca	Remedial Superfund	Creosote PAHs	Incineration	Full	Sensebe 1994 (personal communication)
USA/IL Waukegan	Remedial Superfund	PCBs	Thermal desorption	Full	Hutton and Shanks 1992
USA/OH Ashtabula	Remedial ARCS	PCBs	Thermal desorption	Pilot	U.S. EPA 1993g
USA/NY Buffalo River	Remedial ARCS	PAHs	Thermal desorption	Pilot	U.S. EPA 1993f
Netherlands Elburg	Remedial	Metals	Sintering	Pilot	Van den Eede 1994
USA/NY/NJ Harbor	Navigation	Dioxins, Metals, PCBs, PAHs	Vitrification	Pilot	Jones et al. 1999
USA/NY/NJ Harbor	Navigation	Dioxins, Metals, PCBs, PAHs	Rotary Kiln--Blended Cement Production	Pilot	Jones et al. 1999
			PARTICLE SEPARATION		
USA/MI Saginaw River	Remedial ARCS	PCBs Metals	Screens, Hydro cyclones	Pilot	U.S. EPA 1994d
Canada/ON Toronto	Remedial CSTTP	Metals PAHs	Attrition scrubbers Hydro cyclones	Pilot	U.S. EPA 1993f
Germany Hamburg	Navigation	Metals PAHs, PCBs	Screens, Hydro cyclones, Belt filter	Full	Detzner 1993
Canada/ON Welland	Remediation CSTTP	Metals	Screens, Screw class, Centrifuge	Pilot	Acres International 1993
Netherlands Rotterdam	Remediation	Metals PAHs	Hydro cyclones Settling basins	Pilot	Deibel and Zwakhals 1993

- *Oxidation (of organic compounds):* Involves the use of chemical additives to transform and degrade organic contaminants. Oxidation may be commonly used to treat amines, phenols, chlorophenols, cyanides, halogenated aliphatic compounds, mercaptans, and certain pesticides in liquid waste streams (U.S. EPA 1991c). It may also be used on soil and sediment slurries and sludge (U.S. EPA 1994b).

Specific applications, limitations, specifications, and efficiencies of these processes are discussed more fully in the ARCS Program's *Remediation Guidance Document* (1994b).

Extraction/Washing

The primary application of extraction processes is to remove organic, and in some cases, metal contaminants from the sediment particles. Sediment washing is another term used to describe extraction processes, primarily when water may be a component of the solvent. In the extraction process dredged or excavated material is slurried with a chemical solvent and cycled through a separator unit. The separator divides the slurry into the three fractions: 1) particulate solids; 2) water; and 3) concentrated organic contaminants. The concentrated organics are removed from the separator for post-process treatment. Often the cycle is repeated several times before the treated solids are removed from the process. By separating the contaminants from the solids and water matrix, the extraction process can result in volume reductions of 20-fold or more (U.S. EPA 1994b).

Pre-treatment is often necessary before solvent extraction in order to reduce oversized debris present in the dredged or excavated material. The maximum particle size depends on the scale and configuration of the extraction process, size is process specific and depends on size of equipment. Implementability for most of these processes may be difficult because of limited full-scale development for handling sediment and the problems of solvent recovery and potential toxicity of residual solvents.

Immobilization

Immobilization, commonly referred to as solidification/stabilization, alters the physical and/or chemical characteristics of the sediment through the addition of binders, including cements and pozzolans (U.S. EPA 1994b). Immobilization technologies primarily work by changing the engineering properties of the sediment so that contaminants are less prone to leaching. Alteration of the physical character of the sediment to form a solid material, such as a cement matrix, reduces the accessibility of the contaminants to water and entraps the contaminated solids in a stable matrix (Myers and Zappi 1989). The presence of free water in the original dredged or excavated material may be a large contributor to the initial leachate volume at a disposal site. By binding the free water into a hydrated solid, solidification reduces contaminant losses through leaching (U.S. EPA 1994b).

Solidification with cement has been demonstrated for use on a large scale (greater than 1 million cubic yards) for New York/New Jersey Harbor dredged material (Myers and Adrian 2000). The material was used to cap a Brownfields site and a landfill that was subsequently used for a shopping mall. Chemical characteristics of the solidified sediment should be compatible with the environmental requirements of the reuse project (e.g., cement stabilized sediment may have elevated pH).

Another form of immobilization, chemical stabilization, minimizes the solubility of metals primarily through the control of pH and alkalinity. In some cases, chemical stabilization technologies can decrease the solubility of some metals, but increase the mobility of other metals (Myers and Zappi 1989). Anions, which may be more difficult to bind in insoluble compounds, may be immobilized by entrapment or micro-encapsulation. Chemical stabilization of organic compounds may be possible, but the mechanisms involved are not well understood (Myers and Zappi 1989).

The potential for implementation of immobilization processes is better than other treatment processes because they are not as sensitive to process-control conditions. Stabilization processes have recently been used for contaminated New York Harbor sediment and at the Marathon Battery project. However, bench scale studies are recommended to ensure a successful project. For example, although solidification with lime is a simple process, the ensuing exothermic reaction can drive off volatiles, and/or create steam or dust problems.

Thermal Treatment

Thermal technologies include incineration, pyrolysis, thermal desorption, sintering, and other processes that require heating the sediment to hundreds or thousands of degrees above ambient temperatures. Thermal destruction processes, such as incineration, are effective for destroying organic contaminants, but are also expensive and have significant energy costs. Thermal treatment does not destroy toxic metals. There are chemical processes that destroy organic contaminants, such as reductive dechlorination, but these process are also expensive (and may have significant energy costs).

Thermal desorption processes heat sediment to temperatures of 90°C to 540°C to physically separate volatile and semivolatile organic compounds from sediment. Water, organic compounds, and volatile metals are vaporized by the heating process and subsequently condensed and collected as a liquid, captured on activated carbon, or destroyed in an afterburner. Heating is accomplished using indirectly fired rotary kilns, heated screw conveyors, externally heated distillation chambers, or fluidized beds (U.S. EPA 1991d). The resulting volume of volatilized contaminants should be collected for subsequent treatment.

The Superfund Innovative Technology Evaluation (SITE) program and New York Harbor, and Francingues and Thompson (2000) are evaluating two thermal treatment processes to remove enough contamination from the sediment for beneficial use purposes, such as aggregate. A specific SITE example is the Sediment Melter Technology Pilot-Scale study, which treated 70 tons of PCB-contaminated sediment from the Fox River, produce a glass aggregate material suitable as a foundation material.

Particle Size Separation

Particle size separation involves separation of the fine material from the coarse material by physical screening. A site demonstration of the Bergman USA (U.S. EPA 1994d) process resulted in the successful separation of less than 45 micron fines from washed coarse material and a humic fraction. As noted in the preceding paragraphs, particle size separation may serve as a pretreatment step prior to implementation of a treatment alternative. Many treatment processes require particle sizes of 1 cm or less for optimal operation.

Effluent Treatment/Residue Handling

Treatment of process effluents (liquid/gas/solid) is a major consideration during selection, design, and implementation of dredging or excavation. As shown in Highlight 6-1, dredging or excavation may require management of several types of residual wastes from the pretreatment and operational treatment processes that include liquid and/or air/gas effluents from dewatering or other pretreatment/treatment processes, residual solids and runoff/discharges from active CDFs.

These wastes can be handled through the use of conventional technologies for water, air, and solids treatment and disposal. However, the technical, cost, and regulatory requirements can be important considerations during the evaluation of dredging or excavation as a cleanup method. The project manager should refer to EPA (1994b) for a discussion of the implications and selection criteria for residual management.

Information Resources for Treatment Technologies

The list of potential sediment treatment technologies may continue to change as new technologies are developed and other technologies are improved. EPA has recognized the need for an up-to-date list of treatment alternatives and has developed the following databases:

- *EPA Remediation and Characterization Innovative Technologies (EPA REACH IT):* Provides information on more than 750 service providers that offer almost 1,300 remediation technologies and more than 150 characterization technologies (includes a variety of media, not just sediment). More information is available at http://www.epareachit.org/index3.html; and

- *Risk Reduction Engineering Laboratory (RREL) Treatability Database:* Provides results of published treatability studies that have passed the EPA quality assurance reviews, it is not specific to sediment, and is available from the EPA's Risk Reduction Engineering Laboratory, Cincinnati, Ohio, 45268 and at http://www.epa.gov/ncepihom/Catalog/EPA600C93003A.html.

The NY/NJ Harbor Project is an example of a large-scale demonstration of dredged decontamination technologies. Each of the technologies presented in Highlight 6-11 has demonstrated destruction, removal, or immobilization of organic chemicals and metal contaminants and production of uncontaminated material that could be used in one or more commercial products such as manufactured cement, glass and ceramic tiles, facade bricks, and topsoil (Stern et al. 2000, Mulligan et al. 2001).

Highlight 6-11: NY/NJ Harbor - Treatment Technologies and Beneficial Use

The goal of the NY/NJ Harbor Sediment Decontamination Project is to assemble a complete decontamination system for cost effective transformation of dredged material into an environmentally safe material used in the manufacturing of a variety of beneficial use products.

The following four treatment technologies are being used at the NY/NJ site: 1) sediment washing; 2) thermal treatment; 3) solidification; and 4) vitrification. Each technology has a sponsor from the private sector that will provide the capital needed for facility construction and operation.

Sediment washing (extraction) uses high-pressure water jets and proprietary chemical additives to extract both organic and inorganic contaminants from the sediment. The resulting materials can be used to produce manufactured soil for commercial, and in some cases, residential landscaping applications. The advantages to this treatment are modest capital costs and high throughput. A limitation to this treatment is that to be cost effective, the original sediment has to contain a significant amount of sand.

A thermal treatment being used is a thermo-chemical manufacturing process that, at high temperatures, will destroy organic contaminants. The process will melt a mixture of sediment and modifiers, and the resulting product is a manufactured grade cement comparable to Portland Cement. This is a very effective treatment, but expensive.

A third process is a “treatment train” that includes dewatering, pelletizing, and transport to an existing light-weight aggregate facility. Pelletizing is a type of solidification treatment. After the sediment is dewatered, it is mixed with shale fines and extruded into pellets. The pellets are fed into a rotary kiln, and the organic matter explodes. The resulting material can be used as a structural component in concrete, insulation (pipeline) and for other geotechnical uses.

Finally, the process includes a high temperature vitrification, which uses an electrical current to heat (melt) and vitrify the soil in place. This process can destroy organic contaminants and incorporate metals into a glassy matrix which can be used to produce an architectural tile.

Source: Stern et al. 2000, Mulligan et al. 2001, Stern 2001, NRC 1997

6.7 DISPOSAL

Disposal refers to the placement of dredged or excavated material and process wastes into a temporary or permanent structure, site, or facility. The goal of disposal is to prevent contaminants associated with sediment and/or residual wastes from reentering the environment and impacting human health and the environment. Disposal is a major component of any dredging or excavation alternative. The identification of disposal sites may often be the most controversial component of planning, design, and implementation.

Contaminated sediment is typically managed in upland sanitary landfills, hazardous or chemical waste landfills, CDFs, or CADs. Also, the material may have a beneficial use in an environment other that the aquatic ecosystem from which it was removed (e.g., foundation material beneath a newly constructed Brownfields site), especially if the sediment has undergone treatment.

Highlight 6-12 provides summary descriptions and extent of use for each of these technologies. Additionally, the EPA (1994b) provides a discussion of the available technologies, including an in-depth discussion of costs, design considerations, and selection factors associated with each technology. Averett et al. (1990), EPA (1991b), and Palermo and Averett (2000) provide additional discussion of disposal options and considerations.

Highlight 6-12: Summary of Disposal Technologies

Technology	Description	Use
Sanitary Landfill	Dewatered material disposed of in a properly licensed landfill.	Commonly used for disposal of dredged material and pretreatment/treatment process residuals.
Hazardous/Chemical Waste Landfill	Highly contaminated, dewatered material disposed of in a landfill specially licensed to accept hazardous and chemical wastes.	Commonly used for disposal of dredged material and pretreatment/treatment process residuals.
Confined Disposal Facilities	In-water or upland, diked facility specifically constructed for disposal of dredged material.	Routinely used for disposal of raw dredged material from navigational and remedial projects.
Level-Bottom Capping	Material placed on a flat bottom of a waterbody and covered with a layer of clean sediment.	Used for disposal of contaminated sediment from navigational dredging within Clean Water Act (CWA) 404 jurisdiction.
Contained Aquatic Disposal	Material placed into an excavated or natural depression or underwater diked area and covered with clean material or cap.	Used for disposal of contaminated sediment from navigational and environmental dredging within CWA 404 jurisdiction.
Beneficial Use	Lightly contaminated, raw or treated material used for construction, beach nourishment, or other beneficial uses.	Used infrequently in environmental dredging projects; may be appropriate for treated sediment.

6.7.1 Sanitary/Hazardous Waste Landfills

Existing commercial and municipal sanitary and hazardous waste landfills are one of the most widely used options for disposal of dredged or excavated material and pre-treatment/treatment residuals associated with environmental dredging and excavation. Landfills may also be constructed specifically for use in disposing of sediment from environmental dredging. Landfills can be categorized by the types of wastes they accept and the laws regulating their operation. Most solid waste landfills accept all types of waste (including hazardous substances) that are not regulated as Resource Conservation and Recovery Act (RCRA) hazardous waste or Toxic Substances Control Act (TSCA) toxic materials. Additionally, a limited number of RCRA-hazardous and TSCA-toxic landfills may be available for disposal of hazardous and toxic materials (U.S. EPA 1994b).

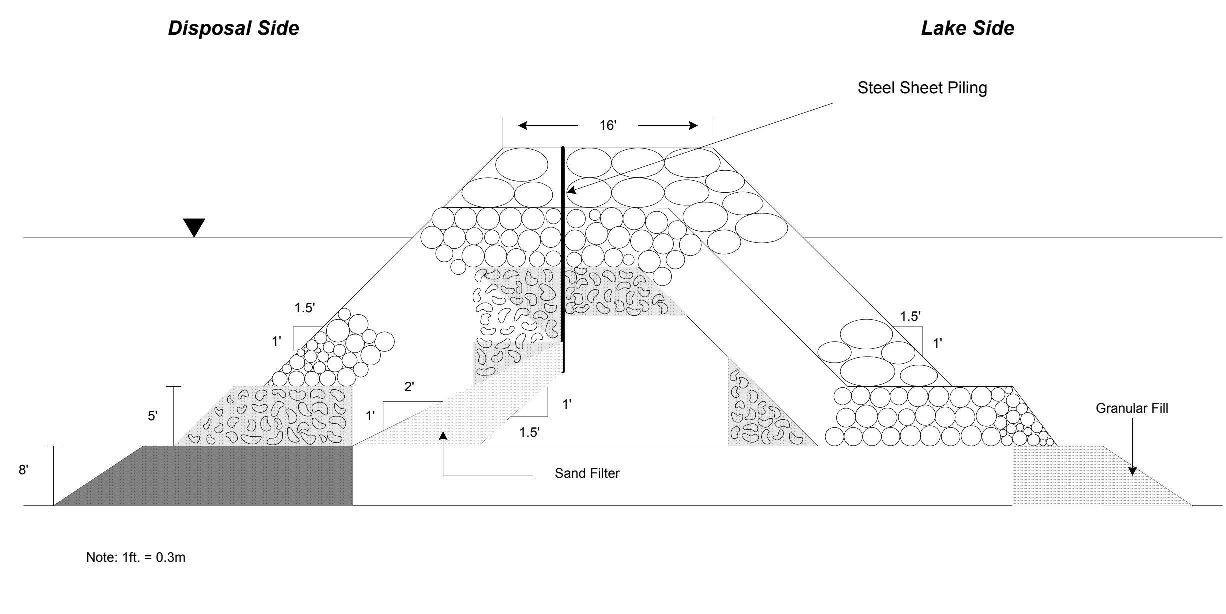
Due to the restriction on liquids in landfills, most dredged material should be de-watered and/or stabilized/solidified before disposal in a landfill. Temporary placement in a CDF or pretreatment using mechanical equipment may therefore be necessary (Palermo 1995).

6.7.2 Confined Disposal Facilities

CDFs are engineered structures enclosed by dikes and specifically designed to retain dredged solids and associated contaminants. Under normal operations, water is discharged over a weir structure or allowed to migrate through the dike walls while solids are retained within the CDF. Typically effluent guidelines or discharge permits govern the monitoring requirements of the return water. Details regarding the engineering design of CDFs to include sizing to retain solids are available in the U.S. Army Corps of Engineers (USACE) engineer manual, *Confined Disposal of Dredged Material* (USACE 1987).

A cross-sectional view of a typical nearshore CDF dike design is shown in Highlight 6-13. CDFs may be located either upland (above the water table), near-shore (partially in the water), or completely in the water (island CDFs). EPA (1996f), EPA (1994b), EPA (1991b), and Averett et al. (1990) contain thorough descriptions, technical considerations, and costs associated with CDFs. Additionally, Black and Veatch (in preparation) contains a history and evaluation of the design and performance of CDFs in the Great Lakes Basin, including a review and discussion of relevant contaminant loss and contaminant uptake studies.

Highlight 6-13: Cross Section of a Confined Disposal Facility Dike with a Filter Layer



Note: Adapted from US. EPA 1998d

6.7.3 Contained Aquatic Disposal

Contained aquatic disposal is a type of subaqueous capping in which the contaminated dredged material is placed into a natural or excavated depression. The depression provides lateral containment of the contaminated material, and also has the advantage of requiring less maintenance and being more resistant to erosion than level-bottom capping. The depression for the CAD cell may be excavated using conventional dredging equipment or natural or historically dredged depressions may be used. Uncontaminated material excavated from the depression may subsequently be used for the cap (U.S. EPA 1994b). The design of a CAD option for a sediment remedy should be approached in the same way as a CAD project design for dredged material disposal and cap designs for in-situ capping (U.S. EPA 1998d, Palermo et al. 1998a, and Palermo 1997). A major consideration is the selection of the appropriate methods for placement of the contaminated material and subsequent placement of the cap. Community acceptance and local land use laws are also important considerations in the siting and placement of CADs.

6.7.4 Losses From Disposal Facilities

Evaluation of a disposal facility for placement of contaminated sediments should include assessment of contaminant migration pathways and incorporation of management controls in the facility design as needed. Landfill disposal options may have short-term releases which include spillages during transport and volatilization to the atmosphere as the sediment is drying. As for any disposal option, longer-term releases depend in large part on the characteristics of the contaminants and the design and maintenance of the facility.

For CDFs, contaminants may be lost via effluent during filling operations, surface runoff due to precipitation, leachate through the bottom, seepage through the dike wall, volatilization to the air, and uptake by plants and animals. The USACE has developed a suite of testing protocols for evaluation of each of these pathways (U.S. EPA and USACE 1992), and these procedures are included in ARCS guidance for estimating contaminant release (U.S. EPA 1996f). The USACE is developing a comprehensive contaminant pathway testing and evaluation manual for CDFs (USACE in preparation). Depending on the likelihood of contaminants leaching from the confined sediment, a variety of dike and bottom linings and cap materials may be used to minimize contaminant loss (U.S. EPA 1991b, U.S. EPA 1994b, Palermo and Averett 2000). CDFs for sediment remediation projects are more likely to need control measures such as bottom or sidewall liners or low permeability dike cores than would CDFs constructed for navigation dredged material.

For CADs, contaminants maybe lost to the water column during placement of the contaminated sediment, and advection of pore water during the initial consolidation of the sediment following placement and capping. Volatilization may also occur at both CDFs and CAD sites during placement. Whatever disposal options are evaluated, the effects of contaminant losses during construction and in the long term should be considered.

6.7.5 Beneficial Use

Beneficial use of dredged or excavated sediment has been implemented infrequently to date as a dredge material management option in association with environmental cleanup. Although not normally considered a disposal option, in special situations, beneficial use may be an appropriate management option for lightly contaminated or treated sediment resulting from environmental dredging projects.

Significant cost saving may be realized if physical and chemical properties of the sediment allow for beneficial use. In each case, the contaminant levels and environmental exposure, including considerations of future land use, should be assessed. For example, at Newburgh Lake, Michigan, significant cost savings were realized by using lightly contaminated dredged material as daily cover at a local sanitary landfill, where the presence of the dredged material did not pose risk within the landfill boundary. Options for beneficial use may include the following:

- Beach nourishment (for a clean sand fraction);
- Construction fill;
- Sanitary landfill cover as in the above example;
- Mined lands restoration (e.g., http://www.dep.state.pa.us/dep/DEPUTATE/MINRES/BAMR/bark_camp/barkhomepage.htm);
- Subgrade cap material (topped with clean sediment or other fill); or
- Building materials (e.g., architectural tile, see Highlight 6-11).

A series of technical notes on beneficial use of contaminated material is currently being developed by the USACE (Lee 2000). Use of contaminated materials from CDFs (to include treated material) is a major thrust of the USACE Dredging Operations and Environmental Research (DOER) program (http://www.wes.army.mil/el/dots/doer/).

In some cases, a CDF can be integrated with site reuse plans to both reduce environmental risk and simultaneously foster redevelopment in urban areas and Brownfield sites. For example, at the Sitcum Waterway cleanup project in Tacoma, Washington, contaminated sediment was placed in a near shore fill, which was then developed into a container storage area. Also, there may be innovative and environmentally protective ways to reuse dredged contaminated sediments in habitat restoration projects (e.g., placement of lightly contaminated material over highly contaminated materials to build up elevations necessary for final placement of clean emergent marshlands).

6.8 SITE CONSIDERATIONS

6.8.1 Physical Environment

Several aspects of the physical environment may make dredging more or less difficult to implement. In the remedial investigation, the following types of information should be collected, as they will affect the type of equipment selected and potentially the feasibility of dredging:

- Bathymetry, slope of the sediment surface and water depth;
- Currents and tides;
- Bottom conditions, especially the presence of debris and large rocks;

- Depth to and (un)evenness of bedrock or hard bottom (e.g., stiff glacial till);
- Sediment particle size distribution and degree of consolidation;
- Thickness of contaminated sediment;
- Distance between dredging and disposal locations;
- The presence of structures such as piers, pilings, cables, or pipes; and
- Land access to waterbody.

Additionally, sediment removal may change the hydrodynamics and slope stability of the remediation area. These changes need to be evaluated to insure that the removal activity does not cause instability or other adverse effects on the system.

6.8.2 Sediment Characteristics

Thorough horizontal and vertical characterization of both the physical sediment characteristics and the contaminants at the site is needed during the remedial investigation to evaluate the feasibility of dredging or excavation. The results of this characterization will help determine the area, depth, and volume to be removed, and the volume of sediment requiring treatment and/or disposal. Some aspects of sediment characterization are discussed in Chapter 2, Remedial Action Considerations.

There are several tests that may help provide the project manager with needed information for design of dredging, treatment, or disposal methods. The project manager should refer to Highlight 6-14 for a summary of the most commonly used tests. In addition, the time and cost needed to conduct engineering and environmental testing should be considered. Several guidance documents on estimating contaminant losses from dredging and disposal have been developed by the EPA and USACE. The project manager should refer to *Estimating Contaminant Losses from Components of Remediation Alternatives for Contaminated Sediments* (U.S. EPA 1996f), *Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. - Testing Manual (Inland Testing Manual)* (U.S. EPA and USACE 1998) and *Evaluation of Dredged Material Proposed for Disposal at Island, Nearshore or Upland Confined Disposal Facilities - Testing Manual* (USACE in preparation) for further information.

6.8.3 Waterway Uses and Infrastructures

Removal of contaminated sediment has the advantage of potentially imposing fewer limitations on waterway uses than capping or monitored natural recovery alternatives. However, any evaluation of the feasibility of a dredging or excavation project should consider impacts to existing and potential future

Highlight 6-14: Dredging/Disposal Feasibility Tests

Test	Description	Data Utilization	Reference
Atterberg Limits	Determines the percent moisture content that sediment changes from a solid to a semi-solid (shrinkage limit), a semi-solid to a plastic (plastic limit), and a plastic to a liquid (liquid limit).	Used in conjunction with other physical properties to determine the potential physical behavior of the sediment during remediation; for example, at moisture contents greater than the liquid limit, the sediment may behave and flow like a viscous liquid.	Spigolon 1993
Pancake Column Leach Test (PCLT)	Water is passed through a sample of the dredged material; after passing through the dredged material, the water is analyzed for contaminant concentrations.	Used with mass transport modeling to estimate the long-term water quality impact and contaminant flux in a confined disposal site.	Brannon et al. 1994
Dredged Material Slurry Settling Tests	Sediment slurry/coagulant mixtures are added to a settling column; height of the sediment/water interface is measured at specific time intervals over a period of time.	Performed to observe the settling behavior of sediment; aids in design of particle settling basins, confined disposal facilities, and sediment dewatering system.	USACE 1987
Effluent Elutriate Test	Aqueous extract is prepared from a sediment/water mixture that is mixed and allowed to settle; the extract is analyzed for its contaminant concentrations (Settling time = Estimated CDF water retention time).	Used to estimate the amount of contaminants that may be released during hydraulic filling of a confined disposal facility.	USACE WES 1998
Moisture Content	A measure of the amount of moisture in a soil sample, calculated as: (wet weight - dry weight)/(dry weight); commonly used in engineering and geological applications.	Used in conjunction with other physical properties when designing and sizing remediation components.	ASTM D2216
Particle Size Distribution	Particles are separated into various size classes, such as sand, silt, clay, by passing them through a series of fine-meshed sieves.	Determines the relative amounts of silts, sands, and clay materials in sediment; has a wide range of implications for pretreatment, treatment, etc.	Spigolon 1993
Specific Gravity	Measurement of the weight of a volume of sediment compared to the same volume of water.	Useful in determining how quickly sediment will sink in water; useful in design sediment dewatering and particle size separation systems.	U.S. EPA and USACE 1998
Standard Elutriate Test	An aqueous extract is prepared from a sediment/water mixture that is allowed to settle for one hour, centrifuged, and decanted; extract is analyzed for its contaminant concentrations.	Used to estimate the amount of contaminants that may be released during dredging and open water disposal.	U.S. EPA and USACE 1977

uses of a waterway. Waterway uses that should be considered when selecting a dredging with treatment or disposal alternative include the following:

- Navigation (commercial, military, recreational);
- Residential/commercial/military moorage;
- Flood control;
- Recreation;

- Fishing;
- Water supply, such as presence of intakes;
- Storm water or effluent discharge outfalls;
- Use by fish and wildlife, especially sensitive or important aquatic habitats;
- Waterfront development;
- Utility crossings;
- Existing disposal sites; and
- Anchorage areas.

Evaluation of the feasibility of a sediment removal project should include an analysis of whether impacts to these uses may be avoided or minimized both during construction and in the long term. For dredge or fill projects being considered within or adjacent to a navigation or flood control channel, the long- and short-term effects of the project on the functions of the channel should be considered. The acceptable draft of vessels allowed to navigate over a contained aquatic disposal should consider water level fluctuations (seasonal, tidal, and wave) and the potential effects of grounding on a cap. Because of the potential erosion caused by propeller wash, restrictions on propeller size and/or vessel draft may be necessary. Anchoring or bottom trawling should not be allowed at locations on or near the contained aquatic disposal site to avoid disturbance of a cap.

6.8.4 Habitat Alteration

The project manager should consider the potential impact of habitat loss or alteration in evaluating a dredging or excavation alternative. While a project may be designed to minimize habitat loss, or even enhance habitat, sediment removal and disposal does alter the environment. However, it is important to determine whether the loss of a contaminated habitat is a greater impact than the benefit of providing a new, modified but less contaminated habitat. For example, a sediment removal alternative may or may not be appropriate where extensive damage to an existing upland or wetland will occur. If the contaminated sediment in the wetland is bioavailable and may be impacting wildlife populations, the short-term disruption of the habitat may be warranted to limit ongoing long-term impacts to wildlife. In this instance, the contaminated habitat as an attractive nuisance may more than offset its positive functional values. On the other hand, if the wetland is functioning properly and is not acting as a contaminant source to the biota and the surrounding area, it may be appropriate to leave it intact rather than remove it. Deliberations as to whether to alter wetland and aquatic habitats should be a routine component in the remedial decision process, and each site offers its own unique considerations. Coordination with natural resource agencies will assist the project manager in determining if the dredging project may impact aquatic organisms or their habitat, and how to minimize these impacts.

Another consideration is avoidance of short-term ecological impacts during dredging. This may involve timing the project to avoid water quality impacts during migration and breeding periods of sensitive species or designing the dredging project to minimize suspended sediment during dredging and disposal.

Habitat impacts are also important when evaluating disposal options. Near shore habitat is often the most sensitive and important habitat to aquatic organisms, and, in many cases, has already been adversely affected by human activity. Filling these areas should be considered only if no other options with less adverse effect on the aquatic environment are available. Examples of projects where filling of wetlands was deemed appropriate to achieve cleanup goals include the Bailey Waste site in Texas City, Texas, where the Record of Decision (ROD) called for filling in marsh areas to make a causeway for excavation equipment to access contaminants that extended from the shoreline out into the marsh. At the New Bedford Harbor, Massachusetts site, a dewatering facility may be constructed in a shoreline area which may also be available for port activities in the future. New Bedford decisions preserve an extensive salt marsh system on the opposite side of the estuary.

Highlight 6-15 presents some general points to remember from this chapter.

Highlight 6-15: Points to Remember When Considering Dredging and Excavation

- Source control generally should be implemented to prevent re-contamination
- A dredging or excavation alternative should include details concerning all phases of the project, including sediment removal, transport, and treatment or disposal options
- Transport and disposal options may be complex and controversial; start investigating options early and discuss them with stakeholders
- In predicting risk reduction effects of dredging or excavation of deeply buried contaminants, the project manager should remember that biota will only respond to removal of contaminants that are bioavailable
- Environmental dredging should be conducted to take advantage of new equipment and methods of operation which minimize resuspension
- Project managers should conduct a site-specific assessment of anticipated sediment resuspension, contaminant release and transport, and its potential ecological impacts prior to dredging
- Project managers should make realistic assumptions regarding residual contamination. Where over-dredging is not possible, residual contamination is generally higher than where this practice is possible
- Excavation (conducted in the dry) often leads to lower levels of residual contamination than dredging (conducted under water)
- The use of experienced operators and oversight personnel skilled in dredging or excavation technologies as well as other phases of the project is very important to an effective cleanup
- A dredging or excavation project should be monitored during implementation to assess resuspension and transport of contaminants, immediately after implementation to assess residuals, and after implementation to measure long-term recovery of biota and test for re-contamination